Space Shuttle Main Engine

The only implementations selected for the Retrofit Alternative were the Vision 2000 Space Shuttle main engine and a new main engine controller. The Vision 2000 Space Shuttle main engine implementation, which has already been approved by the Space Shuttle Program, consists of new Alternate Turbopump Development fuel and oxidizer pumps, a large throat main combustion chamber (MCC), a phase II+ powerhead with a single cooling coil, and block II controller improvements. The Vision 2000 Space Shuttle main engine improvements enable more complete servicing of the engines on the vehicle and allow the engines to remain on the vehicle for up to 10 flights. The new main engine controller implementation goes beyond the changes made in the block II controller. The new main engine controller incorporates the orbiter engine interface unit (EIU) function internally and allows the EIU to be eliminated. The new controllers also provide increased capability for launching with failed transducers by providing a more complex algorithm to determine which transducer is providing a faulty reading and eliminating it from the voting scheme.

The New Build Alternative selected the retrofit implementations along with electro-mechanical actuators for the Space Shuttle main engine thrust vector control (TVC) system and propellant valves. The Space Shuttle main engine's electro-mechanical actuators will work in conjunction with the electro-mechanical actuators used for aerosurface control and landing gear operations on the new-build vehicle. Complete elimination of the hydraulic system on the orbiter is now possible. The Space Shuttle main engine's electro-mechanical actuators would be powered by high-density fuel cells in the same manner as the other electro-mechanical actuators on the vehicle.

External Tank

Implementations for the external tank addressed increased performance and reductions in manufacturing complexity. The first implementation selected was the super-lightweight tank, which adds 8,000 to 12,000 pounds of Shuttle payload performance due to the lower weight of the external tank. An assumption was made that the development of the super-lightweight tank would be implemented by the baseline program.

The manufacturing-related implementations selected include alternative thermal protection system concepts and an electro-magnetic acoustic transducer (EMAT). The thermal protection system alternatives address the use of composites and heat sinks instead of sprayed-on foam. This reduces the labor involved with the thermal protection system application. The EMAT is a new nondestructive technique for weld inspection. This new technique eliminates today's labor intensive dye penetrant inspection. There are opportunities to use the technique in other areas of orbiter processing as well.

Solid Rocket Booster

Solid rocket booster implementations focused on reducing the labor intensive operations associated with processing the boosters. Alternative boosters were considered for replacement of the solid rocket boosters. Boosters considered were the advanced solid rocket motor (ASRM), liquid rocket boosters (LRB's) (LO_2/RP–1), hybrids, and flyback LRB's. The flyback LRB was the only booster configuration that had a life cycle cost comparable with the solid rocket boosters. Discussion of the flyback booster provided is given in the Approach, Ground Rules, and Organization section.

Improvements recommended for the solid rocket boosters included a solid propellant gas generator (SPGG) replacement for the hydrazine auxiliary power units, electro-mechanical actuator replacement of the thrust vector control system along with an alternate power source to replace the hydrazine auxiliary power units, and laser-initiated pyrotechnics. The solid propellant gas generator and electro-mechanical actuator implementations are targeted to eliminate the hydrazine auxiliary power units. Past studies have shown that an electro-mechanical actuator thrust vector control system would net higher annual recurring savings than the SPGG, so this would be the preferred choice. The electro-mechanical actuator thrust vector control eliminates the hydraulics on the solid rocket boosters, as well. The laser-initiated pyrotechnics eliminate elecromagnetic interference (EMI) concerns and enable complete firing circuit verification after firing line connection. The ordnance connections can be performed in the Vehicle Assembly Building (VAB) instead of late in the flow and do not require facility clears.

Ground and Flight Operations

Mass Properties and Performance

The mass properties and performance for the Retrofit and New Build Alternatives were calculated by determining the incremental effects of each implementation chosen. A detailed mass breakdown of Orbiter Vehicle (OV) 105 was used as a point of comparison for the analysis.

Many of the hardware implementations selected require significant changes in the subsystem definitions. Some changes overlap several subsystems. In some instances components are removed, while other combinations add hardware. Most implementations modify the existing components. The avionics implementations reduced the number of components significantly, which reduced the system mass by over 900 pounds. However, other subsystem implementations selected by the Retrofit Alternative offset the mass saving of the avionics system.

The net effect for the Retrofit Alternative was to increase the vehicle mass by 58 pounds. The center of gravity (CG) for the Retrofit Alternative was changed more significantly by the implementations. The landed center of gravity is 5.2 inches aft of the landed center of gravity for OV–105.

The New Build Alternative was permitted to change systems more extensively, including structure. The New Build Alternative landed mass is 2,300 pounds lower than OV–105, but the landed center of gravity remained unchanged.

The performance of the Retrofit Alternative is the same as for OV–105. Approximately 55,000 pounds can be transported to a 100 nautical mile, 28.5 degree orbit. When a super-lightweight tank is used, the lift capability is increased to approximately 63,000 pounds. Performance to a 100 nautical mile orbit at an inclination of 51.6 degrees is approximately 49,000 pounds for the Retrofit Alternative.

The New Build Alternative performance is 2,300 pounds greater than OV–105 or the Retrofit Alternative. The performance to an altitude of 100 nautical miles and an inclination of 28.5 degrees is approximately 57,000 pounds. The performance with a super-lightweight tank is close to 65,000 pounds. The higher performance of the orbital maneuvering system on the new-build vehicle offers more payload capability at higher altitudes than the OV–105 or Retrofit Alternative.

Technology Plan

The Space Shuttle evolution technology and advanced development plan for Option 1 addresses all flight-related subsystems and elements. The key technology and advanced development programs for Space Shuttle evolution are outlined below.

The development of high-temperature thermal protection system elements and/or nonhazardous thermal protection system waterproofing agents is critical to reducing thermal protection system processing costs. Further characterization of TUFI coatings and AETB and ACC tiles is required before implementation can be achieved. Advanced flexible blankets, which will reduce operational costs through increased temperature margins, will need further advanced development work as well.

The development of propellant residue-insensitive valves will significantly reduce orbital maneuvering system/reaction control system unscheduled maintenance operations and costs. Accessing and developing low-toxicity propellants and propulsion systems, both cryogenic and storable, will eliminate many of the hazardous propellant operations at the Kennedy Space Center.

Advanced development and technology initiatives for avionics include the development of flight certified integrated guidance, navigation, and control (GN&C) units using interferometer fiber optic gyro technologies, differential GPS for terminal approach, attitude determination using GPS for inertial navigation system (INS) alignment, digital signal processing component development for communications and space flight-qualified high-definition television components that are lightweight, small volume, and low power.

The data management system must develop stable software and hardware interfaces for integration of commercially available off-the-shelf hardware that will mitigate long-term obsolescence. Improved methods of software development and maintenance must be developed using autocode generation, as well as improved software validation and verification methods.

Development of high-power density fuel cells and high voltage and high current switching technology is required for both the electrical auxiliary power unit and electro-mechanical actuator options. Advanced development of space qualified electro-mechanical actuators and electrical hydrostatic actuators should be pursued.

A technology initiative that produces a Freon-21 replacement that is nonhazardous and environmentally safe is very desirable. The development of cryogenic cooler/boiler and thermal wax pack heat rejection devices, which do not use toxic fluids such as ammonia, should be addressed.

A vehicle health management plan must be developed that focuses Agency technology funding toward specific customer needs. Particular hardware development efforts should address built-in test capabilities for mechanical systems and line replacable unit fault isolation, robust engine health instrumentation and algorithms, on-board leak isolation, smart transducers and sensors, on-board solenoid valve current signature instrumentation, and highly reliable valve position indicators.

Structural characterization of aluminum-lithium and high-temperature aluminums should be pursued.

Development of laser implementation of the NASA standard initiator, pyrotechnic initiator controller, and safe and arm systems will reduce ground operations costs, improve system safety, and reduce the number of anomalies associated with the current pyrotechnic systems.

Many of these technology developments are applicable to new launch vehicle systems as well.

Costing

All cost data is reported in fiscal year (FY) 1994 dollars. Production costs for the solid rocket booster, solid rocket motor, external tank, and Space Shuttle main engine are recurring costs that are reflected in the baseline Space Shuttle Program budget. Wrap factors are in accordance with NASA Comptroller instructions. The program support wrap was reduced to five percent for design, development, test, and evaluation (DDT&E) and 0 percent for production. The NASA Cost Model (NASCOM) was used to estimate DDT&E and production costs and the operations savings were estimated by grass-roots methods.

Recognizing the uncertainties of the study, the following conclusions were reached.

The cost savings identified to date in the Retrofit Alternative are $145M per year. The cost to retrofit the fleet is estimated at $5.7B. Many of the individual changes identified in the Retrofit Alternative should be implemented in any event; however, sufficient data does not exist to recommend implementing the total package of proposed retrofit changes.

The cost savings identified to date in the New Build Alternative are $169M per year. The fleet replacement cost is $15B. The New Build Alternative is not cost-effective, and there are no substantial reasons to build a new fleet. Features contained in the New Build Alternative should be considered if and when a new orbiter is built.

Only the direct hardware-driven costs, about 32 percent of the Space Shuttle Program budget, were addressed by the study. Current operations cost accounting methods were found to be inadequate for accurately determining the savings from subsystem improvements. The NASCOM was not designed for estimating modifications to existing systems, and there are only limited tools available for estimating space flight operations costs.

Several recommendations were developed to improve the cost estimating capability. High quality grass-roots estimates should be developed for high pay-back items. An activity-based cost accounting system should be established to track all operations costs. New cost-estimating relationships (CER's) should be developed to improve the estimating capability in selected areas. An effort should be initiated to develop an operations cost model and a new NASCOM with factors for technical change, process improvements, and design inheritance.

Findings

The Option 1 team found that the Retrofit Alternative was the best of the three alternatives examined. It has the lowest investment cost and about the same savings in operations costs as the others.

Providing additional crew escape capability was not recommended due to cost, weight, and center of gravity impacts, and technical risks. Several means to reduce costs further and increase fight safety were identified. One is an uncrewed orbiter, which would allow the flight rate to increase without impacting human safety, permit more flexible flight and payload assignment, increase the payload capability of the Shuttle system for uncrewed cargo delivery. Another is to replace the solid rocket boosters with flyback liquid boosters, which could increase safety and simultaneously improve operations efficiency.

The uncrewed orbiter has already had considerable definition, but the flyback booster requires further study to define cost effectiveness.

The Shuttle system is safe and highly reliable, and could support the projected national mission model through 2030. However, if the nation is to place primary reliance on the Space Shuttle for this period, the current four orbiter fleet is not sufficient. Detailed plans must be made for either orbiter replacement upon attrition or immediate expansion of the fleet size.

Many technologies have been identified that could prove useful to other concepts for future space transportation. Associated technology development should be initiated soon. Examination of new ways of doing business to address non-hardware potential efficiencies should proceed and be carried out by the Space Shuttle Program Office. Improvements to accounting methods and cost data bases should also be undertaken.

Option 2 Team Analysis

Objectives and Approach

The conventional technology options are requirements-driven architectures (with 1997 technology) that can replace the current launch systems in approximately 2005. These new architectures are to meet the nation's total space transportation needs—civil, national defense, and commercial—and to provide improved crew safety, acceptable life-cycle costs (affordable design, development, test, and evaluation; improved operability and annual cost reduction; and acceptable program risks), and a mission reliability of 0.98, and be environmentally acceptable. The architectures should improve commercial competitiveness, contribute to the industrial economy, enable incremental development/improvements, and provide improved capability relative to current systems.

The Option 2 approach was a multiphased process consisting of the spacecraft portion and the launch vehicle portion. Mission options that dealt with crew and cargo logistics were down-selected to three main architectural categories: (1) separate crew and cargo airframe, (2) common crew and cargo airframe with HL–42 vehicle, and (3) common crew and cargo airframe with CLV–P vehicle. Each mission option placed different requirements on the launch vehicle families.

The launch vehicle down-select process began with 84 vehicle families that were narrowed to 28, based on performance and propellant selection criteria. The 28 families were assessed in a one-on-one comparison for each mission category based on cost, safety, environment, risk, operability, and reliability. Four architectures were selected for detailed costing and were defined and analyzed. They are illustrated in figure 15.

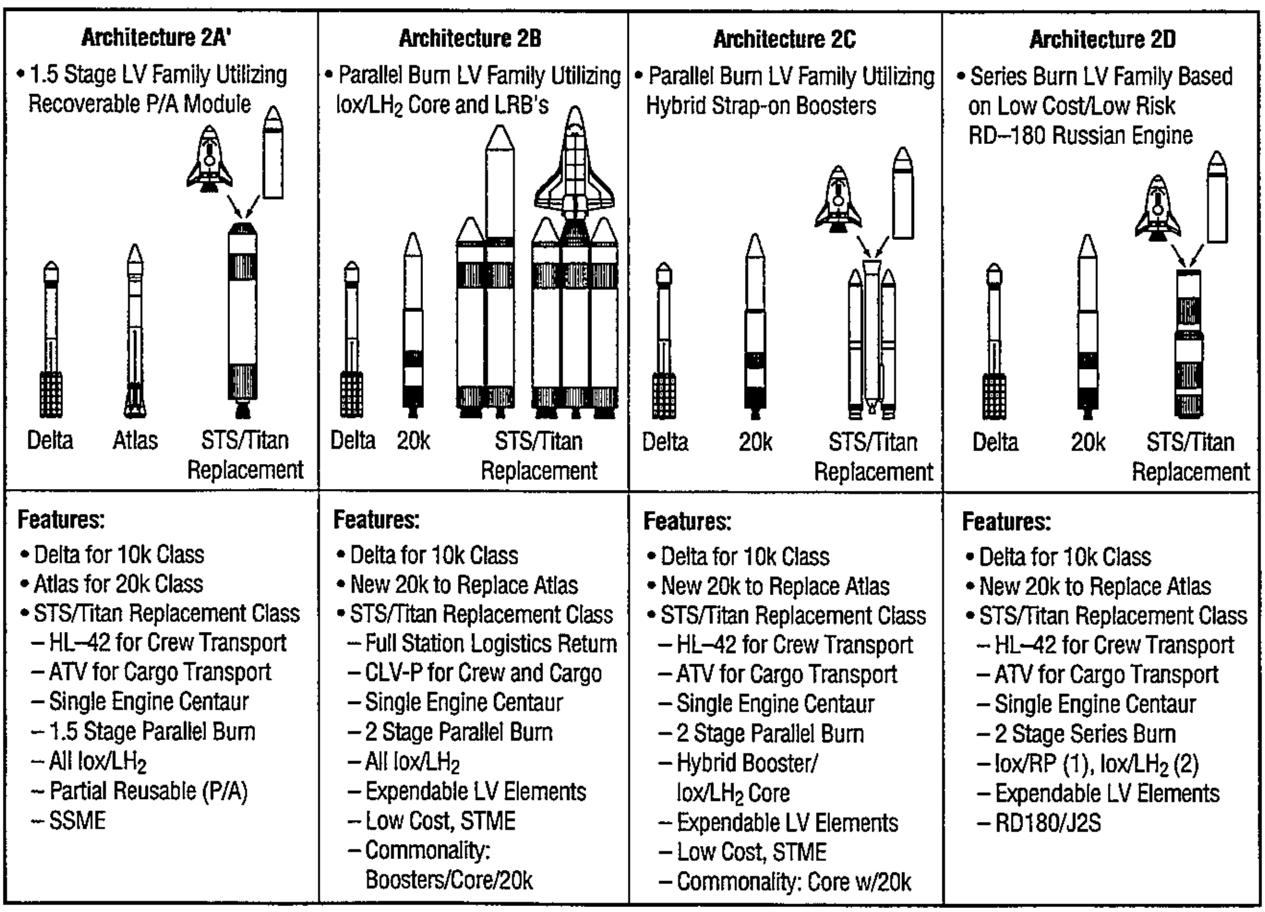


FIGURE 15.—Option 2 architecture overview.

Architecture Overview

The nation's access to space is provided in 10k, 20k, and 65k pounds to low-Earth orbit (LEO), and 15k pounds to geosynchronous transfer orbit (GTO) classes. All architectures feature the Delta launch vehicle for the 10k-pound class payloads. The 20k-pound class is provided by using the Atlas launch vehicle for Architecture 2A'. Architectures 2B, 2C, and 2D use a new booster with commonalty to the STS/Titan IV (TIV) replacement and a single-engine Centaur upper stage. The Space Shuttle/TIV replacement architectures are as follows: 2A'—1.5 stage with recoverable propulsion/avionics modules and reusable Space Shuttle main engines; 2B—a hydrogen-fueled parallel burn two-element vehicle that uses a liquid booster for the TIV-type missions and two liquid boosters for the STS-type missions; 2C—a parallel burn two-element vehicle using a hydrogen fueled core and hybrid boosters; 2D—a two-stage series burn vehicle with a rocket propellant (RP) fueled booster and a hydrogen fueled second stage. Architectures 2A', 2C, and 2D use a small lifting body reusable personnel launch system (HL–42) for crew transport and a cargo transfer vehicle for cargo transport. Architecture 2B uses a reusable CLV–P (approximately 70-percent scale of the STS orbiter) for transport of crew and payloads.

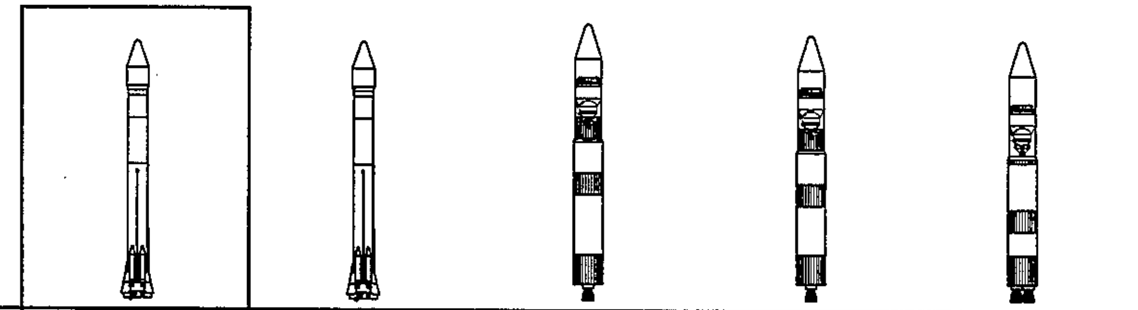
Major Features of Architectures

20k Class Vehicle Comparisons

The 20k vehicle alternatives are compared in figure 16. For Architecture 2A', the Atlas (with evolutionary upgrades) remains throughout the mission model period. At a cost of $85M per flight, the Atlas represents an acceptable approach if the reliability (0.89) and operational features are improved. Architectures 2B and 2C use a 20k vehicle replacement based on a hydrogen/oxygen booster with a modified Centaur upper stage (incorporates single RL-10C and structurally stable tankage with a calculated reliability of 0.99). The booster is 18 feet in diameter and uses a new low-cost space transportation main engine. The Architecture 2D 20k vehicle replacement is based on an RP–1/oxygen booster with a modified Centaur upper stage with a calculated reliability of 0.98.

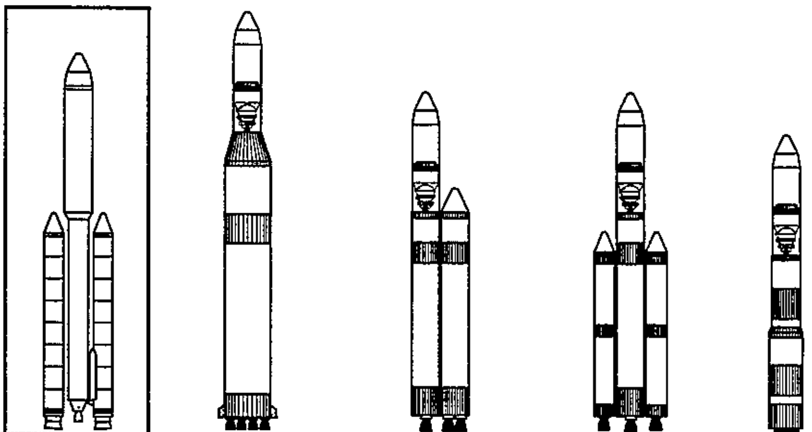
Titan IV-Class Vehicle Comparisons

Titan IV-class alternatives are compared in figure 17. For Architecture 2A', the vehicle replacement is a high reliability (0.98) 1.5 stage hydrogen/oxygen vehicle based on a 27.5 foot external tank diameter. The propulsion system is comprised of a cluster of six Space Shuttle main engines configured in 3 two-engine propulsion/avionics (P/A) modules. The two booster modules are jettisoned during ascent and recovered, while the third performs the sustainer role and is recovered after main engine cutoff. For Architecture 2B, the vehicle is an L-configuration core with single booster. The all hydrogen/oxygen vehicle utilizes a stretched 20k core (18-foot diameter) with a single 700k pound thrust engine on the core and two on the booster, and has a calculated reliability of 0.98. For Architecture 2C the vehicle is a highly reliable (0.99) parallel-burn core with hybrid boosters. The hydrogen/oxygen core is a stretched 20k core with a single 700k-pound space transportation main engine, and the boosters produce 1.5M pounds of thrust with a pump-fed oxygen supply and hydroxyl terminated polybutylene (HTPB) propellant. Architecture 2D uses a two-stage series burn vehicle with a calculated reliability of 0.98. The RP–1/oxygen first stage is 27.5 feet in diameter and utilizes RD180 engines. The second stage is a Saturn IV–B class stage, 20 feet in diameter, and uses a single J2–S engine.



Vehicle	Atlas IIAS	Option 2A' (Atlas IIAS)	Option 2B	Option 2C	Option 2D
Booster	Castor IVA (HTPB)	Castor IVA (HTPB)	—	—	—
Stage 1	Atlas Booster (MA–5A)	Atlas Booster (MA–5A)	lox/LH_2 (Low Cost, STME)	lox/LH_2 (Low Cost, STME)	lox/RP (RD–180)
Stage 2	Atlas Sustainer (MA–5A)	Atlas Sustainer (MA–5A)	—	—	—
Upper Stage	Centaur (2 RL–10A)	Centaur (2 RL–10A4)	Centaur (1 RL–10C)	Centaur (1 RL–10C)	Centaur (1 RL–10C)
GLOW (klbs)	516	516	495	462	727
Payload (Orbit)	17,775 (100 × 100 nmi at 28.5°)	17,775 (100 × 100 nmi at 28.5°)	19,060 (100 × 100 nmi at 28.5°)	18,896 (100 × 100 nmi at 28.5°)	21,660 (100 × 100 nmi at 28.5°)
Average Cost/Flight	$115M	$115M	$92M	$92M	$85M

FIGURE 16.—20k launch vehicle comparison.



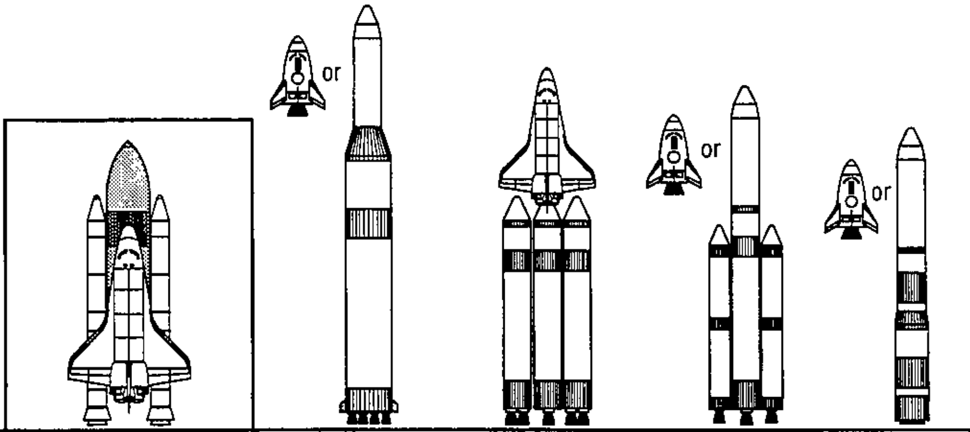
Vehicle	Titan IV	Option 2A'	Option 2B	Option 2C	Option 2D
Booster	SRMU	P/A Module (SSME)	lox/LH_2 LRB (Low Cost, STME)	Hybrid (lox/HTPB)	lox/RP (RD–180)
Stage 1	NTO/A50 (LR–87)	lox/LH_2 (ET) (SSME)	lox/LH_2 (Low Cost, STME)	lox/LH_2 (Low Cost, STME)	lox/LH_2 (J–2S)
Stage 2	NTO/A50 (LR–91)	—	—	—	—
Upper Stage	Centaur (2 RL–10A)	Centaur (1 RL–10C)	Centaur (1 RL–10C)	Centaur (1 RL–10C)	Centaur (1 RL–10C)
GLOW (klbs)	1,886	1,980	1,480	2,410	2,060
Payload to GEO (lbs)	12,700	19,750	14,198	20,917	20,917
LEO 100×100 nmi at 28.5° (No Upper Stage)	47,700	72,051	45,636	76,836	83,583
Average Cost/Flight With Upper Stage	$275M	$119M	$152M	$149M	$151M
Average Cost /Flight Without Upper Stage	$225M	$76M	$108M	$103M	$104M

GLOW–Gross Lift-off Weight SRMU–Solid Rocket Motor Upgraded

FIGURE 17.—Titan IV launch vehicle comparison.

Space Station *Freedom* Logistics Vehicle Comparison

The Space Station *Freedom* crew logistics vehicle comparison is presented in figure 18. For Architecture 2A′, the STS replacement is identical to the Titan replacement vehicle. For cargo applications, the launch vehicle, a Cargo Transfer Vehicle (CTV), shroud, and support equipment are mounted on the launch vehicle. For crew missions, the HL–42 is mounted on top of the core. The vehicle has a calculated reliability of 0.99. For Architecture 2B, the STS replacement vehicle is a parallel-burn core and with two liquid boosters. The CLV–P is flown uncrewed on cargo flights. For Architecture 2C, the Space Transportation System replacement is the same core with hybrid boosters used for Titan missions. For cargo missions, a CTV, shroud, and support equipment are utilized. The HL–42 flies on crew rotation missions. For Architecture 2D, the STS and TIV replacement vehicles are identical. For cargo missions, a CTV shroud and support equipment are utilized, while the HL–42 flies on crew rotation missions.



Vehicle	Shuttle	Option 2A'	Option 2B	Option 2C	Option 2D
Booster	ASRM	P/A Module (SSME)	lox/LH_2 LRB (Low Cost, STME)	Hybrid (lox/HTPB)	lox/RP (RD–180)
Core	Super Light-Weight ET (SSME)	lox/LH_2 (ET) (SSME)	lox/LH_2 (Low Cost, STME)	lox/LH_2 (Low Cost, STME)	lox/LH_2 (J–2S)
GLOW (klb)	4,540	1,970	2,470	2,400	2,070
Payload (lb) to 51.6°					
• Gross to 15×220 nmi	—	76,609	112,487	77,119	84,900
• Net Logistics to S.S. *Freedom*	41,000	61,600*	22,000	62,119*	69,900*
Average Cost/Flight					
• For Crewed Flight	$400M	$105M	$154M	$133M	$133M
• For Logistics Flight	$400M	$196M	$154M	$224M	$224M

* Net Payload to S.S. *Freedom* is reduced by 15,000 lb for ATV aerospace support equipment

FIGURE 18.—Space Station *Freedom* logistics vehicle comparison.

Assessment and Down-Select

The assessment of the Option 2 architectures focused on the issue of logistics return. Full return capability drives cost by requiring a large payload systems (PLS) capability (CLV–P) that needs a 100k-pound launch vehicle or by requiring a high flight rate (20 per year) of an HL–42 PLS. Minimum logistics return capability allows for cost optimization of the architecture. For full return, Architecture 2B is the only option, while 2A′, 2C, and 2D meet minimal return requirements. The cost trade can be summed up as comparing the minimal return lower recurring cost launcher/HL–42 and associated throw-away hardware ($200M per year Space Station *Freedom* logistics and $50M per flight for ATV) with the higher design, development, test, and evaluation/recurring cost of the 100k-pound launcher/CLV–P.

Space Station Logistics
Current plans call for over 200k pounds of Space Station *Freedom* logistics to be delivered annually. The actual logistics mass, including sub-element packaging but excluding carriers is approximately 150k pounds per year. However, the central issue relative to access to space is the return mass. The current baseline, excluding logistics carriers, is 127k pounds. Analysis conducted by Langley Research Center (LaRC) has shown that the baseline return might be lowered from 127k pounds to 65k pounds by judicious return of spares, user, and crew systems.

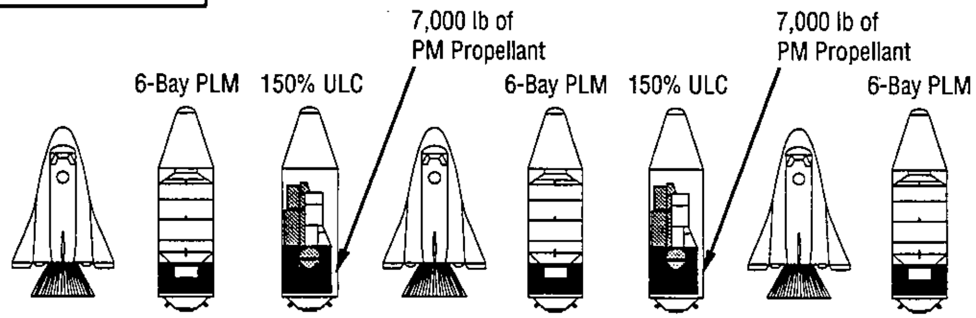
The 65k return requirement consists of the three categories (crew systems, users, and spares). Each category was examined with LaRC and a return rationale was developed that emphasized the return of user payloads. All spares/maintenance were disposed along with five crew systems racks. The full complement of nine EVA suits would be returned. The result is that approximately 22k pounds of logistics would be returned. This would require three HL–42 flights per year for return mass. The acceptability of this level of return (approximately 15 percent of delivered mass) represents an issue that should be addressed in the final Space Station *Freedom* logistics scenario.

Space Station *Freedom* Logistics Manifesting
A typical yearly Space Station *Freedom* manifest for Architecture 2D is shown in figure 19. The eight flights deliver the required up-logistics and use the HL–42 for crew rotation and selected logistics returns. Propulsion module (PM) propellant (7k pounds twice per year) is delivered. Every five years, the full PM would be delivered (nine total flights) to replace life limited hardware. Modified logistics carriers—six-bay pressurized logistics module (PLM) and 150-percent length unpressurized logistics carrier (ULC)—were needed to achieve this yearly Space Station *Freedom* logistics support. Finally, this manifest returned the 78 middeck lockers, extravehicular activity suits, and approximately 65 percent of the user pressurized racks. The 2.8k pounds of user unpressurized logistics were not returned.

Architecture Elements
The separation of crew and cargo has been studied by NASA for the past several years. The primary focus was to minimize crew exposure by not flying a crewed vehicle, thus eliminating crew system constraints for cargo-only missions. Personnel launch systems (PLS) vehicles tended to be small vehicles having very limited cargo capability. Designs varied from parachute recovery concepts (Biconic and Spacecab) to precision (runway) landers (HL–20 and HL–42). Cargo transfer and return (CTRV) vehicle designs ranged from vehicles capable of cargo capacity similar to the orbiter (medium CTRV, winged CTRV/, and vertical lander) to smaller concepts (e.g., Spacecab, Caboose, integral CTRV). The CTRV concepts included both vehicles recovered by parachutes (medium CTRV, Spacecab, and Caboose) to precision lander (winged CTRV and vertical lander). Additionally, some design concepts combined crew and cargo (crew logistics vehicle (CLV)) were also investigated. The concepts were scaled versions of the current orbiter. Early in this study, it was recognized that precision landers were preferable for higher reliability and minimizing operations cost. This down-selection of concepts eliminated all parachute landing and reduced the number of PLS concepts from nine to three (HL–20, HL–42, and CLV) and CTRV concepts from 10 to three (Winged CTRV, HL–42, and CLV).

Personnel Launch System
The down-selection process was derived from the Option 2 mission requirements and from design issues that surfaced during the study. Precision lander (runway landing) concepts were selected over parachute landing concepts to reduce the operations costs associated with parachute landing concepts. Powered vertical landing vehicles were not selected, based on risk. Smaller, less efficient crew/cargo vehicle concepts were eliminated in favor of the best

Reusable PM Steady-State Logistics



Elements	HL–42 (1)	PLM (1)	ULC (1)	HL–42 (2)	PLM (2)	ULC (2)	HL–42 (3)	PLM (3)
Equivalent S.S. *Freedom* Racks	1	25		2	25		1	25
Middeck Lockers	64			50			64	
Carrier Plus Logistics Mass (klb):	63	44	39	63	44	39	63	44
CTV Mass (klb)	0	15	15	0	15	15	0	15
Integrated P/L Mass (klb)	63	59	54	63	59	54	63	59

- During steady-state station operations ~14,000 lb of propulsion module propellant is delivered each year on two ULC flights.

Current estimate yearly logistics = 178 middeck lockers, 79 racks, 3 fluid carriers, 4 dry carriers, cargo, and propellant = 150k lb.

FIGURE 19.—Steady State Space Station *Freedom* delivery/return using HL–42 plus ELV.

combination for separate crew cargo (the HL–20 and CTRV combination) and the best two concepts for combined crew/cargo (the HL–42 and CLV–P concepts). Final selection was based on a greatly reduced cargo return requirement from Space Station, which enabled the crew/cargo HL–42 concept to meet the Option 2 mission requirements at a significantly reduced cost.

Crew Logistics Vehicle

The CLV–P class of spacecraft evolved based on: (1) The Space Station requirements, and (2) maximizing Shuttle heritage while upgrading systems to reflect today's technologies. The fundamental requirements to limit design, development, test, and evaluation cost resulted in the common airframe approach. A scaled version of the current orbiter minimized vehicle cross section, while still allowing accommodation of a Space Station propulsion module and a wing loading not to exceed the current orbiter wing loading for landing speed considerations. The CLV–P is a 70-percent scaled orbiter vehicle with a gross mass of 106,800 pounds, as shown in figure 20.

Vehicle Design

The basic vehicle structure is aluminum, with the rudder, speed brake, and body flap constructed of advanced carbon-carbon (ACC). The thermal protection system includes blankets, TUFI-coated tiles, and ACC for the nose cap and wing leading edges. An integrated orbital maneuvering system and reaction control system was selected using liquid oxygen and a hydrocarbon fuel such as ethanol. Electro-mechanical actuators are used for aerosurface control, landing gear actuation, braking, and nose-wheel steering. Electrical power is obtained from long-life fuel cells for base power and high-power density fuel cells for electromechanical actuator power. The avionics architecture employs an integrated flight management unit with an inertial navigation system (INS), global positioning system, radar altimeter, and an air data system.

Weight Estimate

CLV–P	**(Pressurized Configuration)**
Structure	24,447
TPS	12,627
Propulsion	2,373
Electric Power	6,430
Control	1,368
Avionics	2,021
Environment Control	6,693
Other	4,116
Growth	9,011
Dry Weight	**69,085**
Consumables and Payload	
Propellant	8,975
NonPropellant	2,136
Noncargo Prov.	7,192
Cargo	17,000
Gross Weight	**104,387**
Launch Vehicle Adapter	1,720
Total Launch Weight	**106,107**

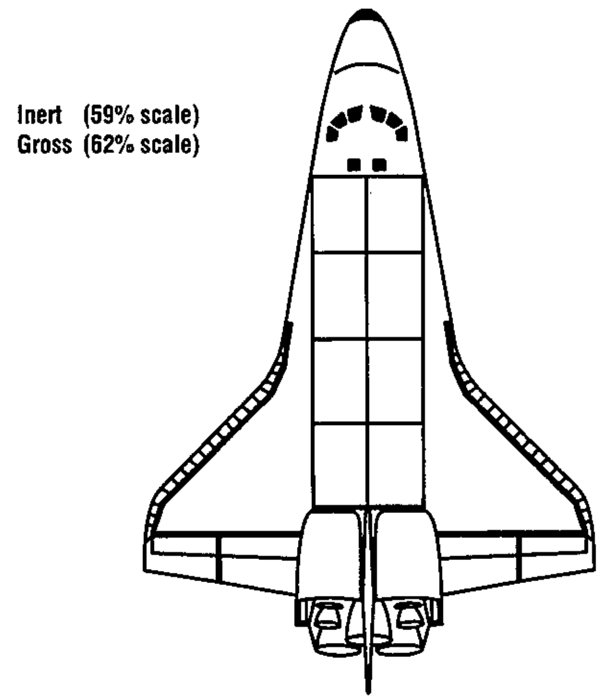


FIGURE 20.—CLV–P design.

Mission Analysis and Aborts

A detailed mission analysis was completed resulting in a mission timeline, required delta-v and cross range, and landing opportunities. The nominal crew logistics vehicle mission will last 4 days, 20 hours from launch to landing, allowing some 99 hours docked to the Station. The on-orbit maneuvering propellant budget was sized for a delta-v of 844.6 fps. With weather alternate landing sites at Edwards Air Force Base and White Sands, the minimum cross range required for a nominal mission is 306 nautical miles. Abort capability is provided through ejection seats for low-altitude aborts and intact abort capability through the remainder of the ascent.

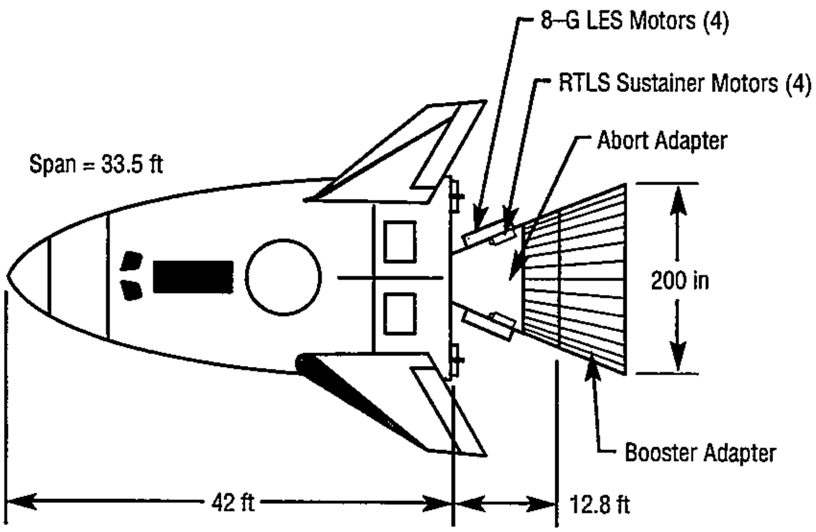
HL–42

The HL–42 design stems directly from the HL–20 lifting body vehicle concept under study since 1983 at Langley Research Center. It is a 42 percent dimensional scale-up of the HL–20, and retains key design and operational features of the HL–20 design. The applicable HL–20 design data base includes extensive NASA aerodynamic, flight simulation and abort, and human-factors research, as well as results of contracted studies with Rockwell, Lockheed, and Boeing in defining efficient manufacturing and operations design.

Vehicle Design

The HL–42, shown in figure 21 is a reusable lifting-body spacecraft with launch escape motors (for aborts) attached to the expendable launch vehicle adapter at the base of the HL–42.

The core of the HL–42 design is an aluminum, cylindrical, pressurized cabin that contains the crew and/or cargo. It has ingress/egress hatches at the top and rear of the cabin. Docking at the Space Station occurs at the rear of the HL–42. A 53-inch Space Station hatch permits loading and unloading of cargo as large as Space Station racks. Extending from the pressurized cabin are frame extensions that support the lower heat shield structure and define subsystem bays. A multipiece titanium heat shield structure defines the underside of the HL–42, with the Thermal Protection System (TUFI tiles) bonded directly to the titanium. The upper surface is composed of aluminum honeycomb removable panels that define the required aerodynamic shape and allow access to the subsystems located in the unpressurized bay areas. AFRSI thermal protection system is bonded directly to these panels. The titanium fins have direct bond thermal protection system (TUFI and FRSI) with the addition of advanced carbon-carbon for the higher heating leading edges. The vehicle nosecap is also made of advanced carbon-carbon.



Weight (lb)	
HL–42 Dry:	29,470
Consumables:	7,748
Crew/Payload:	9,300
On-Orbit:	**46,518**
Abort Motors:	10,870
Adapters:	5,961
Total at Launch:	**63,349**

FIGURE 21.—HL–42 design.

Flight control consists of seven moving surfaces—four body flaps, two elevons on the large fins, and an all-moving center vertical fin. Control movement is effected using electromechanical actuators. Spacecraft power is supplied by hydrogen-oxygen fuel cells with limited emergency power backup provided using rechargeable silver-zinc batteries. The HL–42 propulsion consists of a methane (CH_4) liquid oxygen orbital maneuvering system and reaction control subsystem for multiaxis attitude control on orbit and during entry . The CH_4-liquid oxygen system was selected to delete hypergolic propellants and decrease operations cost.

Mission Analysis and Aborts

The HL–42 spacecraft is launched by an expendable booster into a 15 by 220 nautical mile injection orbit inclined at 51.6 degrees. The orbital maneuvering system capability is 950 feet per second, consistent with maneuvers required to transfer to a 220 nautical mile Space Station orbit, circularization, rendezvous, and deorbit. Various combinations of crew and cargo (Space Station racks, early/late access lockers, and extended memory unit suits) may be carried by HL–42 in the pressurized cabin volume.

Crew safety and intact recovery are two aspects of abort addressed by the HL–42 design. The launch escape motors located on the launch vehicle adapter provide a high-thrust impulse to rapidly distance the HL–42 from a catastrophic booster event. While the HL–42 is on the launch pad and during the first 60 seconds of ascent, these abort motors provide for a return-to-launch site (RTLS) capability and an intact runway landing. Some booster options also provide additional return-to-launch site capability beyond this initial period. Also, limited transatlantic (TAL) and abort-to-orbit (ATO) options exist near the end of the ascent-powered trajectory. However, for a significant portion of the ascent, with some architectures, the abort mode may result in an ocean ditching using emergency parachutes on board the HL–42. Under these conditions it is assumed the vehicle is expendable (not refurbished if recovered). Based on the flight rate, this event is estimated to occur only once in the mission model, with this vehicle attrition accounted for in the fleet sizing.

Cargo Transfer Vehicle

The nominal transfer vehicle reference mission is to provide uncrewed logistics resupply to the Space Station and to destructively reenter with or without trash from the Station. The transfer vehicle must also provide the capability to deliver replacement modules to the Space Station and to destructively reenter excess module hardware. A transfer vehicle function is required in Option 2 architectures 2A′, 2C, and 2D as the prime method of Space Station logistics delivery as well as replacement module delivery. In Architecture 2B, the transfer vehicle function is required only for module replacement/disposal.

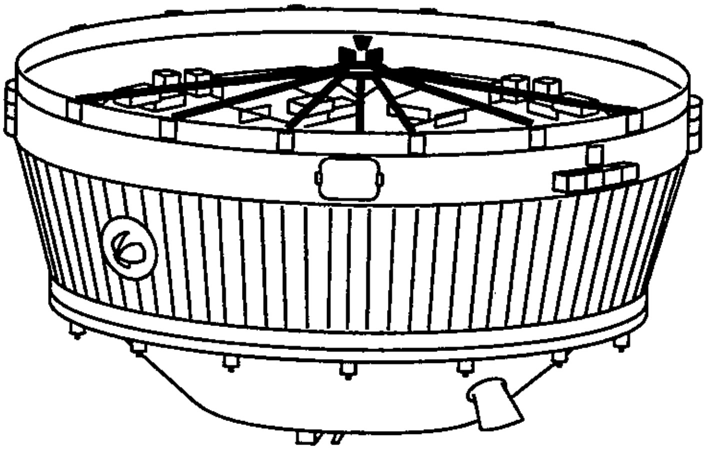
Existing and future spacecraft (both foreign and domestic) with potential for use as transfer vehicles were assessed. Three candidate systems met the mission requirements: U.S. Cargo Transfer Vehicle (CTV from the National Launch System baseline design), European Automated Transfer Vehicle (ATV), and the Russian Salyut Space Tug. Detailed information was assembled for both the U.S. CTV and the ATV designs. Salyut Space Tug information was inadequate for this study.

Comparative analysis of the U.S. CTV and the ATV indicated that the systems were essentially equal in performance and per-flight costs. However, the ATV design, development, test, and evaluation costs are the responsibility of the Europeans, whereas the U.S. CTV design, development, test, and evaluation costs drive the peak funding requirements at the time when requirements are the highest due to personnel launch systems and launch vehicle development funding. In addition, the ATV provides an avenue for *quid pro quo* payment of part or all of the European share of the Space Station operations costs. Thus, the ATV (figure 22) was judged to be the most cost-effective way to satisfy the transfer vehicle function required by Option 2. Launch of the ATV from Kennedy Space Center using a U.S. launch vehicle was judged to be the most cost-effective way to use the ATV in all architectures for Option 2.

Operations

Operations Ground Rules and Guidelines

Johnson Space Center, Kennedy Space Center, Langley Research Center, and Marshall Space Flight Center jointly established ground rules and guidelines that are consistent with an operationally efficient launch system and reduced operations costs. In order to minimize ground operations costs, the following items were eliminated from design consideration: solid rocket motors as core and booster stages; hydraulics; and hydrazine/N_2O_4 systems. An integrated health management system was baselined to accomplish ground test and checkout with minimum personnel time and in one to two shifts. All vehicle and payload elements would be delivered to the launch site in flight-ready condition, with no open work. Test and checkout procedures at the launch site that duplicate those operations accomplished at the manufacturing facility have been eliminated. A crew chief approach is implemented at the



Dry Weights by Subsystem	(kg)	(lb)
Propulsion	587	1,292
GN&C	112	246
DHS	68	150
Communications	46	101
Power Supply	262	576
Mechanisms	95	209
Thermal Control	40	88
Structure	516	1,136
ATV Dry Mass	1,726	3.798
Margin (10%)	172	378
ATV Dry Mass W/Margin	1,898	4,176

Propellant Budgets	Propellant		Wet ATV	
For Composite ATV/Cargo Mass	(kg)	(lb)	(kg)	(lb)
21 Metric Tons	2,983	6,563	4,881	10,738
25 Metric Tons	3,756	8,263	5,654	12,439

Figure 22.—European Automated Transfer Vehicle.

launch site and the responsible launch site system/subsystem engineer provides the quality assurance sign-off for the systems. After initial operating capability (IOC), only "make-safe" and "make-it-work" design changes would be implemented. A block upgrade philosophy will be implemented to account for obsolescence and for cost reduction changes to the fleet.

Significant programmatic ground rules are: NASA operations support center exists only at mission control; ascent monitoring is accomplished at the launch site, with hand-over to mission control at payload separation; after initial operating capability, all government project/program support is at the launch site by one organization and the sustaining engineering is at the launch site; there is one logistics system for all elements; and configuration control is highly automated.

Significant portions of mission operations will be accomplished through the use of automatic systems. Launch, ascent, on-orbit operations, entry, and landing are automated and require no crew intervention, thus reducing cost by eliminating major requirements for facilities and crew training. Payload interfaces and procedures, mission planning, mission manifesting and premission products are simplified and standardized. Ground management of onboard systems will be reduced by automation and onboard vehicle health management. Trajectory and navigation management are decreased by using the Global Positioning Satellite system.

Ground Operations

All Option 2 vehicles will use the integrate/transfer/ launch (ITL) method of processing. The launch vehicle is vertically assembled and interfaces checked in the Vehicle Assembly Building (VAB). Once assembled, all systems will be functionally checked by an onboard autonomous test of the mechanical and fluid system, as well as electronic systems. Crewed spacecraft are prepared for flight in one of the Orbiter Processing Facilities (OPF) and transferred to the VAB for mating with the launch vehicle. Both LC39 pads will be modified to conduct Option 2 launches.

Adoption of the "ready for flight" approach to launch operations for the boosters effectively reduces the size of each option's launch crew; however, flight readiness testing and attendant cost must be accounted for under manufacturing. The "ready for flight" requires delivery of a "clean vehicle" with no open discrepancies or modifications. Additional staff reductions were realized by applying commercial support to hands-on personnel ratios. Commercial ratios are on the order of three-to-one compared to more than six-to-one for today's Shuttle. As the number of people were reduced through lower support ratios and less testing, so were the number of facilities necessary to house them.

Option 2 decreases the current number of facilities and requires no new facilities. Decreasing the number of facilities carries with it a very significant cost reduction. Not only are facilities reduced because of lower staffing levels and less testing, but they are further reduced by the fact that none of the families in the option use solid motors. Without solid motors, the entire Vehicle Assembly Building can be used to house people and conduct parallel processing. Seven solid motor buildings and more than 70 trailers and boxcars would be closed.

The most logical launch site to modify for a 20k vehicle is Complex 40 and its Vertical Integration Facility (VIF). Although no formal or informal agreement with the U.S. Air Force exist for Option 2, this location is ideal since it is an integrate, transfer, and launch layout similar to the Kennedy Space Center and meets Air Force requirements.

Mission Operations

The proposed flight control and monitoring systems for the vehicles of the Option 2 architecture offer a unique opportunity to significantly change the current procedures for conducting mission operations. These changes must be given serious consideration in order to significantly reduce the operational life cycle cost of today's flight systems. It is believed that the technology of the proposed systems will be available during the development phase of the flight vehicles.

Primarily, it is the incorporation of internal vehicle health monitoring and control systems and the Global Positioning System that gives the capability to revise current mission operations procedures. Internal vehicle health monitoring and control systems are practical because of the technology advances in onboard computer systems. The Global Positioning Satellite is a proven system that provides instantaneous information on the position and attitude of the vehicle. This information revolutionizes the navigation and guidance processes for space vehicles. With the advent of these new technologies, the roles of flight crews and controllers can be significantly reduced.

The Option 2 flight scenario assumes that the Kennedy Space Center will be responsible for the flight of the expendable booster systems. Flight monitoring by the Johnson Space Center occurs when the vehicle has separated from the booster system (generally occurs at orbital insertion). Autonomous systems that had targeted the booster to the separation point would transfer control to the orbital vehicle's autonomous system. This system would calculate the orbital insertion and steer the vehicle to that position. The vehicle would than proceed to the next pre-defined phase of the mission. This sequence would continue until all the mission events had been completed. Ground monitors will have the capability to terminate any phase and re-initialize the autonomous flight system with new instructions.

The mission operations would require two facilities: a mission control center and a central simulation facility. These facilities will be designed to support a minimum of 12 flights per year. Design should provide for flight rate increase without major interference with current operations. The mission control center would not be responsible for payload operations. Only 10 to 12 console monitoring and control positions would be required. No requirements for real-time multipurpose support rooms have been identified. The mission control center would not be used for dedicated training. All training would be conducted in the central simulation facility. Training facilities should mirror flight control facilities for flight monitor